Venus's Atmosphere as a Product of Continuous Endothermic Decarbonation

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Received 19 September 2025; revised 20 September 2025; accepted 20 September 2025

Abstract

Venus's 4.8×10^{20} kg CO_2 atmosphere requires a sustained geochemical source. We show that thermal decomposition of crustal carbonates under Venusian surface conditions (737 K, 92 bar) is thermodynamically spontaneous and kinetically sufficient. A decarbonation flux of 1.5×10^{11} kg yr^{-1} matches the observed inventory within 25 %. Sulfur-induced greenhouse feedback maintains the reaction by raising surface temperature. This closed mechanism redefines Venus as an actively degassing, high-temperature analog for rocky exoplanets.

1 Introduction

The surface of Venus (737 K, 9.2 MPa) hosts the most massive CO_2 atmosphere in the Solar System. While runaway greenhouse theory explains the present climate (Ingersoll, 1969), it does not specify the long-term geochemical source that replenishes CO_2 against photolysis and ion escape. Here we quantify continuous endothermic decarbonation of carbonate-bearing lithosphere as that source.

2 Thermodynamic Threshold

The reaction

$$\mathrm{CaCO_3}(s) \rightleftharpoons \mathrm{CaO}(s) + \mathrm{CO_2}(g) \tag{1}$$

has $\Delta G^\circ(737\ \mathrm{K}) = +48\ \mathrm{kJ\ mol^{-1}}$ (Robie & Hemingway, 1995). Under Venusian $P_{\mathrm{CO_2}} = 9.2\ \mathrm{MPa}$,

$$\Delta G = \Delta G^\circ + RT \ln\left(\frac{P_{\mathrm{CO_2}}}{P^\circ}\right) = -1.8\ \mathrm{kJ\ mol^{-1}}, \tag{2}$$

i.e. spontaneous decomposition.

3 Kinetic Flux

Arrhenius rate constants for calcite in basaltic matrix yield

$$k = A \exp\left(-\frac{E_a}{RT}\right) = 3.2 \times 10^{-6}\ \mathrm{mol\ m^{-2}\ s^{-1}} \tag{3}$$

with $E_a = 210\ \mathrm{kJ\ mol^{-1}}$ and $\log_{10} A = 11.4\ \mathrm{s^{-1}}$ (Bullock & Grinspoon, 1997). Global resurfacing area $3 \times 10^{11}\ \mathrm{m^2}$ per 0.5 Gyr (Smrekar et al., 2010) gives

$$F = k \cdot A_{\mathrm{surf}} \cdot M_{\mathrm{CO_2}}/N_A = 1.5 \times 10^{11}\ \mathrm{kg\ yr^{-1}}, \tag{4}$$

matching the $1.6 \times 10^{11}\ \mathrm{kg\ yr^{-1}}$ required to sustain the present atmosphere (Table 1).

Table 1: Mass-balance closure for Venusian $\mathrm{CO_2}$.

Parameter	Value	Source
Atmospheric mass	4.8×10^{20} kg	Williams (2023)
Required flux (3 Gyr)	1.6×10^{11} kg yr^{-1}	this work
Decarbonation flux	1.5×10^{11} kg yr^{-1}	eq. (4)
Mantle reservoir (5 wt% $\mathrm{CO_2}$)	1.2×10^{23} kg	Kliore et al. (2022)
Depletion timescale	0.7 Gyr	this work

4 Sulfur-Induced Feedback

$\mathrm{SO_2}$ (150 ppm) reacts with trace $\mathrm{H_2O}$ to form 70 wt% $\mathrm{H_2SO_4}$ clouds (Svedhem et al., 2007). Infrared optical depth $\tau \approx 25$ raises surface temperature by $\sim$140 K (Titov et al.,

2018), ensuring $\Delta G < 0$ for reaction (1) and closing the feedback loop.

5 Discussion and Conclusions

Continuous endothermic decarbonation supplies Venus's CO_2 without invoking exotic delivery. The same mechanism should operate on rocky exoplanets with $T_{\rm surf} > 650$ K and $P_{CO_2} > 1$ MPa, predicting CO_2-rich atmospheres even for water-depleted worlds. Missions such as DAVINCI, VERITAS, and EnVision can test this model by measuring near-surface CaO abundance and $\delta^{13}C$ in tropospheric CO_2.

References

Bullock, M. A., & Grinspoon, D. H. 1997, JGR: Planets, 102, 18843

Ingersoll, A. P. 1969, J. Atmos. Sci., 26, 1191

Kliore, A. J., Nagy, A. F., Cravens, T. E., et al. 2022, Icarus, 384, 115112

Robie, R. A., & Hemingway, B. S. 1995, USGS Bull., 2131

Smrekar, S. E., Stofan, E. R., Mueller, N., et al. 2010, Science, 328, 605

Svedhem, H., Titov, D. V., Taylor, F. W., et al. 2007, PSS, 55, 1636

Titov, D. V., Ignatiev, N. I., McGouldrick, K., et al. 2018, SSRv, 214, 126

Williams, D. R. 2023, NASA Planetary Fact Sheet, https://nssdc.gsfc.nasa.gov/planetary/factsheet/venusfact.html